

**2002 R&D 100 AWARDS  
ENTRY FORM**

**1. Submitting Organization**

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AFFIRMATION: I affirm that all information submitted as a part of, or supplemental to, this entry is a fair and accurate representation of this product.

Submitter's signature \_\_\_\_\_

**2. Joint entry with**

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\* Work performed under contract NAS8-97238 RSRM Buy 4, Marshall Space Flight Center

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**3. Product name:** **Thermal barrier/seal for extreme temperature applications.**

**4. Briefly describe (25 words or less) what the entry is (e.g. balance, camera, nuclear assay, etc.)**

Braided carbon fiber thermal barrier/seal capable of blocking extreme temperature (5500°F) gases from reaching temperature-sensitive components.

**5. When was this product first marketed or available for order?** September 2001

An invoice for the sale of the thermal barrier is provided in Appendix 1 for reference.

**6. Principal Developers**

List additional developers from all companies on a separate sheet in an appendix and check here. ☒

See Appendix 2 for additional developers.

<b>Name</b>	<b>Bruce Steinetz</b>	<b>Patrick Dunlap</b>	<b>Jack Phelps</b>
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**7. Product price** \$150/foot

**8. Do you hold any patents or patents pending on this product?**

Yes Patent Pending

No

9. Describe your product's primary function as clearly as possible in one page. What does it do? How does it do it? What theories, if any, are involved?

**Reason for Innovation?** Large solid rocket motors, as found on the Space Shuttle (Fig. 1a), are fabricated in segments for manufacturing considerations, bolted together, and sealed using conventional Viton O-ring seals. Similarly the large solid rocket motor nozzles are assembled from several different segments, bolted together, and sealed at six joint locations (Fig. 1b) using conventional O-ring seals. The 5500°F combustion gases are generally kept a safe distance away from the seals by thick layers of phenolic or rubber insulation. Joint-fill compounds, including RTV (room temperature vulcanized compound) and polysulfide filler, are used to fill the joints in the insulation to prevent a direct flow-path to the O-rings (Fig. 2a). Normally these two stages of protection are enough to prevent a direct flow-path of the 900-psi hot gases from reaching the temperature-sensitive O-ring seals. However, in the current design 1 out of 15 Space Shuttle solid rocket motors experience hot gas effects on the Joint 6 wiper (sacrificial) O-rings. Also worrisome is the fact that joints have experienced heat effects on materials between the RTV and the O-rings (Fig. 3a), and in two cases O-rings have experienced heat effects. These conditions lead to extensive reviews of the post-flight conditions as part of the effort to monitor flight safety.

**What?** We have developed a braided carbon fiber thermal barrier (Figs. 2b, 3b, & 4) to replace the joint fill compounds in the Space Shuttle solid rocket motor nozzles to reduce the incoming 5500°F combustion gas temperature and permit only cool (~100°F) gas to reach the temperature-sensitive O-ring seals (see Appendix 3).<sup>1-6</sup> Implementation of this thermal barrier provides more robust, consistent operation with shorter turn around times between Shuttle launches. The new thermal barrier provides the following benefits over current joint fill compounds:

- Allows joint to pressurize with cool gas and seals the joint from pressure fluctuations that would normally drive the internal temperature to unacceptably high levels.
- Prevents 5500°F combustion gas jets from reaching temperature-sensitive primary O-ring seals as demonstrated in full-scale solid rocket motor tests (Fig. 5).
- Enables joint assembly in one-sixth of the time of previous approaches with a much higher degree of reproducibility.
- Increases Space Shuttle safety margins, promoting safety of the astronaut crew and the \$5B Shuttle launch system.

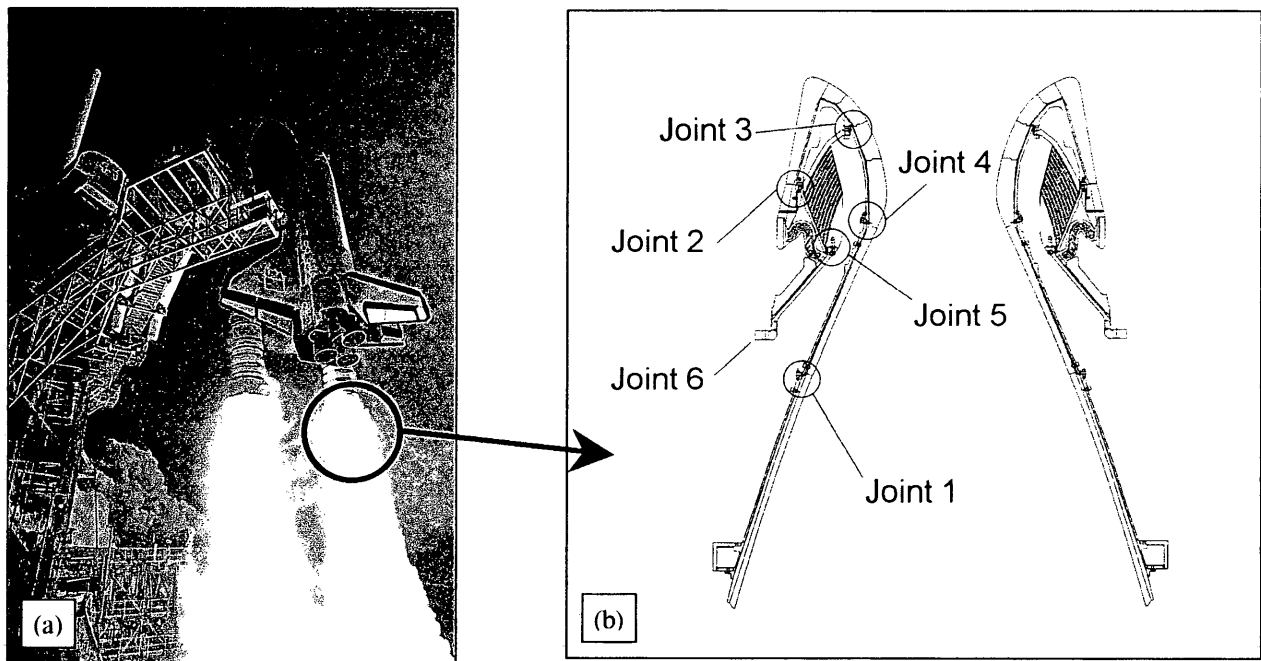
**How?**

- **Temperature resistance:** The carbon fibers used in the thermal barrier have a sublimation temperature of 6900°F in a non-oxidizing environment, 1400°F hotter than the rocket combustion gas temperature of 5500°F. Screening tests using a 5500°F oxyacetylene torch (Fig. 6) showed the superior temperature resistance of carbon fibers over any competing fibers.
- **Unique structure:** The unique braided structure permits designers to tailor the thermal barrier/seal's properties. Tighter, denser braids form a more effective flow restriction. Looser braids offer more flexibility and allow tighter bend radii.
- **Size:** Solid rocket motor designers can specify different cross-sectional diameters (e.g., 0.26 in.) of the braid simply by adding or subtracting braid layers. The thermal barriers are braided in long linear lengths (Fig. 7). Upon installation the thermal barrier is cut to the desired length for a given joint diameter (e.g., 4.8 to 8.5 ft). This promotes easy transfer of the basic design to other rocket and industrial applications.
- **Flexibility/Resiliency:** The carbon thermal barrier provides much-needed flexibility and resiliency to accommodate either joint closings or openings during rocket pressurization and launch not afforded by competing approaches.
- **Self-seating feature:** Tests have shown that upon joint pressurization, the thermal barrier seats itself in the groove to provide a more effective barrier to hot gas flow.

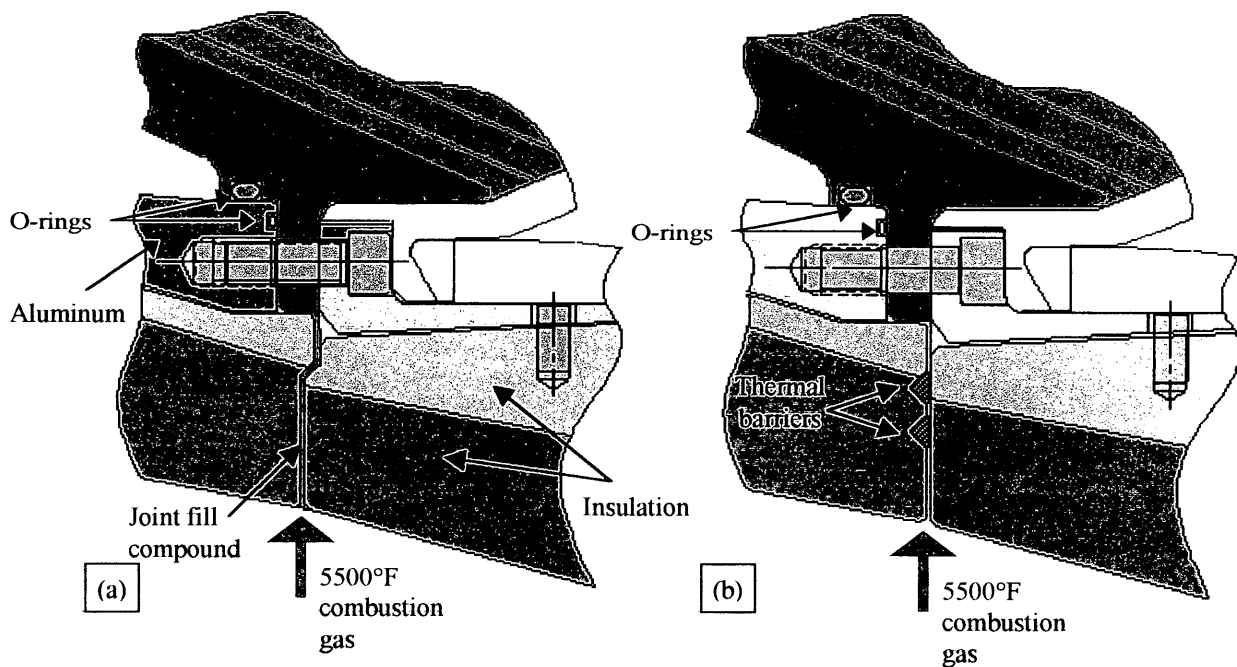
**Why effective?** The carbon thermal barrier is highly effective in this solid rocket motor application for several reasons:

- **Environment:** Carbon fibers are ideally suited to this non-oxidizing environment. They can withstand the high temperatures without experiencing charring, weakening, or other forms of degradation.
- **Elimination of cure:** Current joint fill compounds are manually applied in the joints and require a cure cycle. Unfortunately this cure often leaves pores in the compound that during operation can insidiously connect to focus hot gas jets on the temperature-sensitive O-rings. The thermal barrier eliminates the problems of the RTV process.
- **Temperature drop:** The thermal barrier provides a large 2200°F temperature drop across a single diameter (e.g. 0.26" cross-sectional diameter) reducing the temperature to the downstream O-rings to acceptable levels.

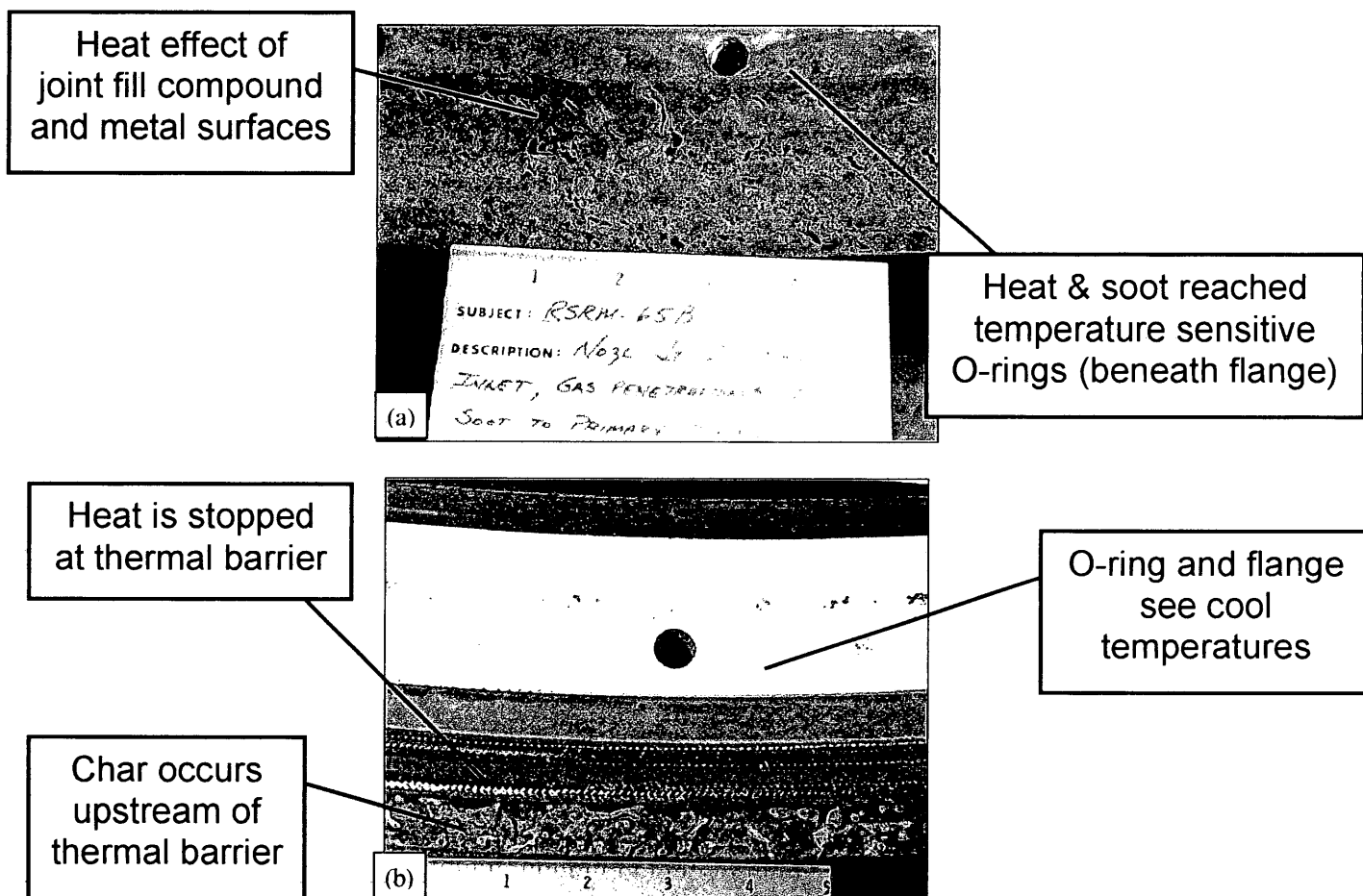
These features taken together distinguish the thermal barrier as a superior approach for preventing O-ring and joint heat effects. Designers of solid rocket motors and special purpose industrial equipment now have an effective new means of limiting the flow of extreme temperature gases.



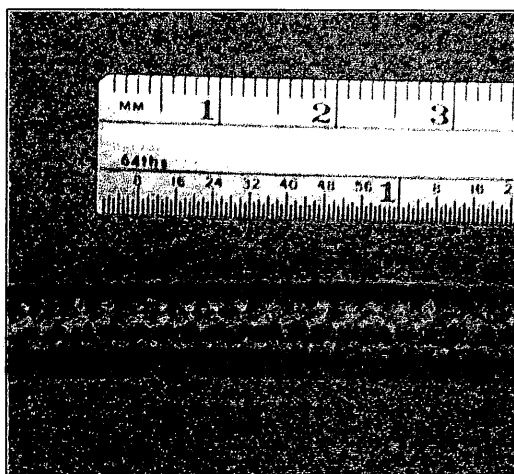
**Figure 1:** (a) Space Shuttle at lift-off propelled by two reusable solid rocket motors (thrust: 3 million lb each), (b) Schematic of Space Shuttle reusable solid rocket motor nozzle with joint locations identified.



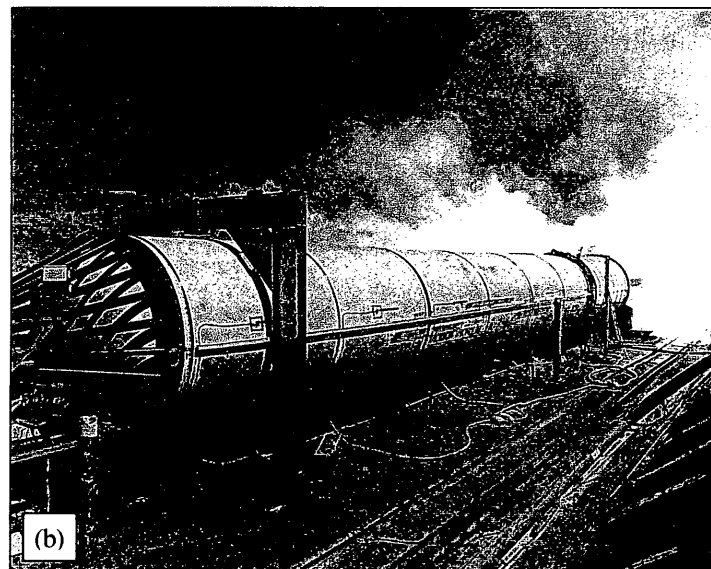
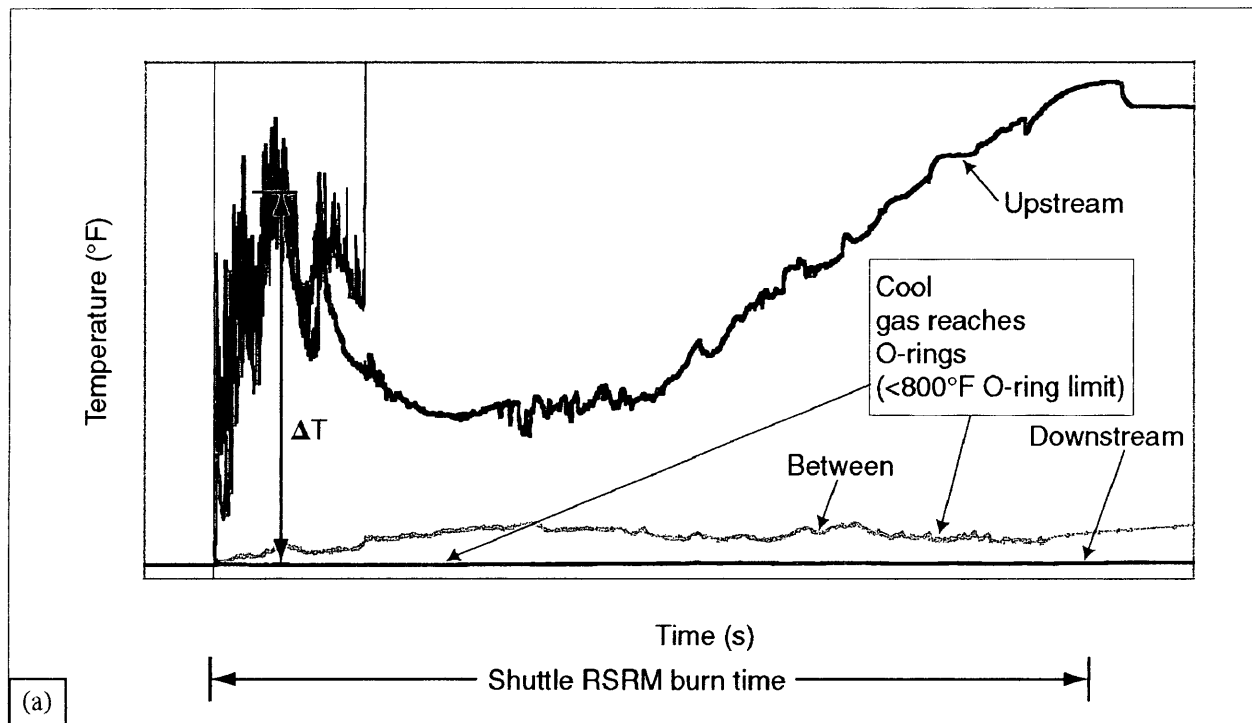
**Figure 2:** (a) Cross section of original nozzle Joint 2 design showing phenolic insulation, metallic substructure, O-rings, and RTV joint fill compound, (b) Cross section of redesigned nozzle joint 2 showing replacement of RTV joint fill compound with dual carbon thermal barriers.



**Figure 3:** (a) Post-flight photograph of Joint 2 showing heat-affected phenolic insulation, RTV, and paint. Soot and heat reached O-ring (beneath metal flange). (b) Post-test photograph of Joint 2 showing hot gas effects upstream of thermal barrier and no heat effects downstream. Metal flange and O-rings beneath flange remained in like-new condition. (Reference Joint 2 after 2001 full-scale solid rocket motor test)



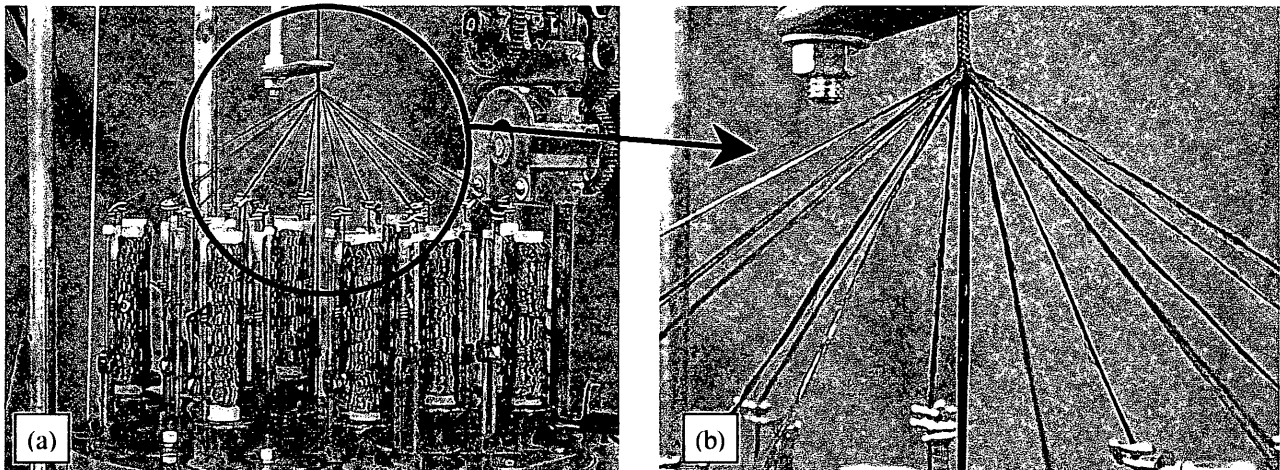
**Figure 4:** Photograph of 0.26-inch diameter carbon thermal barrier.



**Figure 5:** (a) Joint 2 temperature versus time data showing temperatures upstream of thermal barrier, between thermal barriers, and downstream of thermal barriers (~100°F). Downstream temperatures are well within the 800°F short-term temperature limit of Viton O-ring material. (Reference November 1, 2001 full-scale test, see also web page citation in Appendix 4) (b) Photo of full-scale solid rocket motor static test.



**Figure 6:** 5500°F oxyacetylene torch flame on thermal barrier.



**Figure 7:** (a) Photograph of braiding equipment used to produce the carbon thermal barrier,  
(b) Close-up of carbon fibers being braided to form thermal barrier.

**10A. List your product's competitors by manufacturer, brand name and model number.**

There are no known competitors to our carbon thermal barrier capable of standing up to the challenging Shuttle solid rocket motor environment. The highest temperature alternative available during the development process was a ceramic thermal barrier/seal developed by NASA and Albany-Techniweave for turbine and hypersonic engine applications. As indicated in the comparison table presented below, ceramic thermal barriers fall far short of the superior capabilities of the carbon thermal barrier for the challenging solid rocket motor environment.

**10B. Supply a matrix or table showing how the key features of your product compare to existing products or technologies. Include both numerical (data) and descriptive (written) comparisons.**

Feature	Products			
	Our Product:	Current Approach:	Alternate:	Competitive Advantage of Our Product
	Carbon thermal barrier/seal	RTV and polysulfide joint fill compounds	Ceramic thermal barrier/seal	
Prevention of O-ring/joint heat effect	Excellent	Problematic	See Note 1	Carbon thermal barrier prevents O-ring & joint heat effects and prevents molten (3700°F) alumina from penetrating joint.
Temperature capability	$\geq 6000^{\circ}\text{F}$ (non-oxidizing environment)	$\sim 500\text{--}800^{\circ}\text{F}$	$< 2500^{\circ}\text{F}$	Operates up to 5000°F hotter than competing products
Temperature drop across thermal barrier	$\geq 2200^{\circ}\text{F}$	$\sim 1000^{\circ}\text{F}$	See Note 1	Carbon thermal barrier reduces gas temperatures that reach O-rings to acceptable levels
Time to assemble	4 hrs per joint	24 hrs per joint	See Note 1	Time to assemble carbon thermal barrier is 6 times less due to better design.
Joint reproducibility	Installs properly first time with minimal technician training	Joints rebuilt on average 1 time per 5 solid rocket motor builds	See Note 1	Joint more reproducible promoting reliable, safe operation.
Self-seating ability	Self-seats under pressure load	Does not self-seat. RTV does not accommodate joint openings.	See Note 1	Pressure seats thermal barrier in gap to improve performance.
Fault tolerance	Excellent	Poor	See Note 1	Carbon thermal barrier protects O-rings even with 0.05" cut (e.g. fault) in it
Tensile strength	Carbon strength 530 ksi	RTV strength 0.2 ksi. Polysulfide strength less than 0.2 ksi.	Ceramic strength 290 ksi	Carbon strength is almost 2X ceramic strength, and 2600X RTV strength

Notes

1. This feature was not evaluated for the ceramic thermal barrier/seal due to unsatisfactory burn resistance.



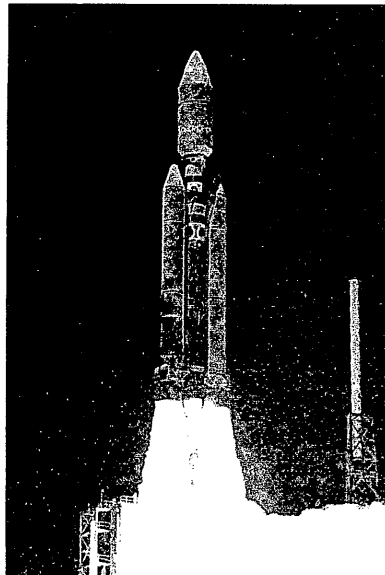
**10C. Describe how your product improves upon competitive products or technologies. BE SPECIFIC! Include such items as how much faster, how much less cost, etc.**

The benefits of our thermal barrier over competing products include the following:

- Prevents 5500°F combustion gases from reaching temperature-sensitive O-rings.
- Diffuses and spreads incoming high-pressure (900 psi) combustion gas jets preventing damage to downstream O-rings.
- Operates up to 5000°F hotter than existing products (e.g. RTV joint filler) without charring or stiffening.
- Exhibits burn resistance over 60 times greater than similarly constructed ceramic thermal barriers.
- Blocks molten alumina (3700°F) slag from impinging on temperature-sensitive O-rings.
- Installs easily into joints in 1/6<sup>th</sup> the time eliminating current laborious, time-consuming steps of applying joint fill compound, checking joint fill integrity, and replacing/repairing joint fill.
- Exhibits excellent fault tolerance: Full scale motor tests demonstrated the effectiveness of the thermal barrier in blocking hot gas jets from reaching O-rings even with a 0.05-in cut through the thermal barrier.
- Provides all of the above benefits for about the same cost as the joint fill compound when considering materials and labor.

**11A. Describe the principal applications of this product.**

- Space Shuttle solid rocket motors
  - No other thermal barrier is able to sustain the 5500°F 900 psi combustion gases generated in the large 12 ft diameter, 126 ft long, 3 million lb thrust Space Shuttle solid rocket motors.
- Expendable solid rocket motors for large space launch vehicles (Fig. 8).
- All future solid rocket motors assembled from multiple segments.

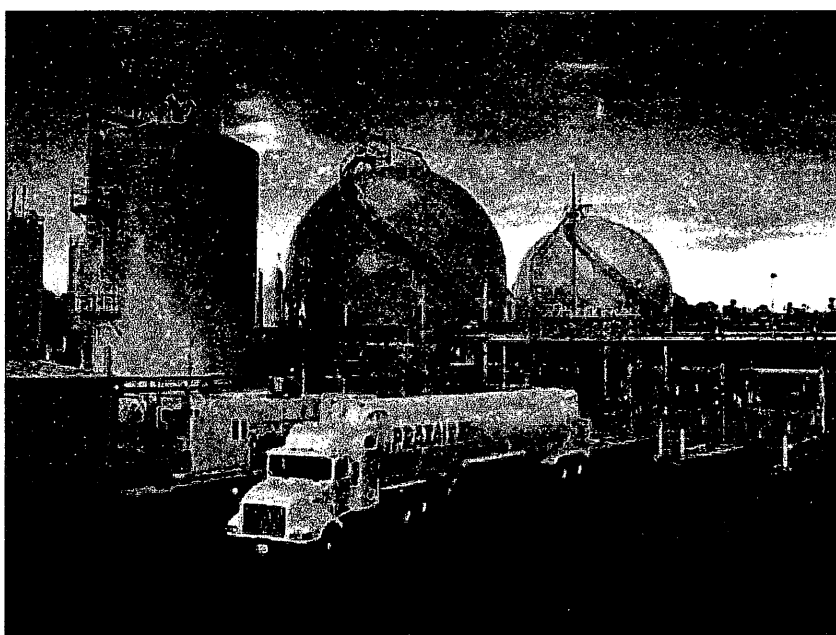


**Figure 8:** Space launch vehicle

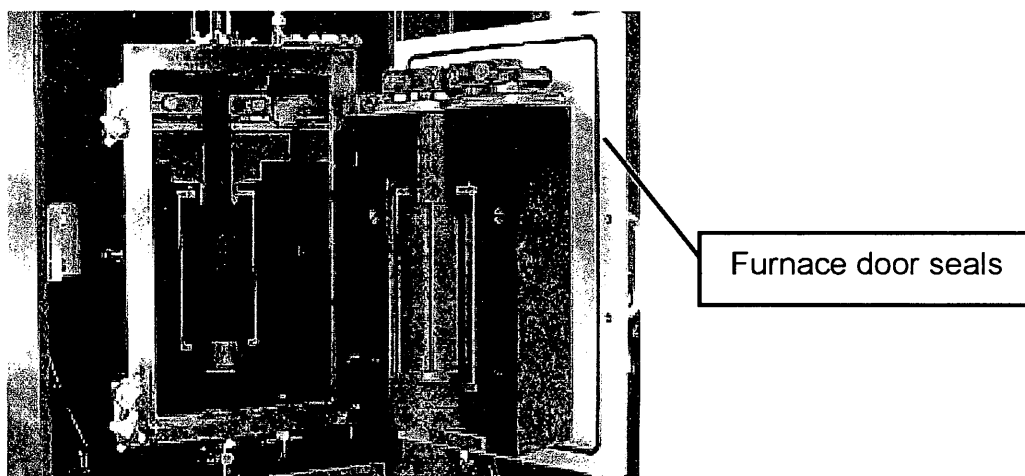
**11B. List all other applications for which your product can now be used.**

- Sealing structural interfaces and sealing glands of processing equipment in the chemical industry where either the high temperatures or highly corrosive environment may disqualify standard polymeric or metal seals but where the carbon rope seal would survive (Fig. 9).
- Sealing furnace doors to prevent leakage of potentially dangerous super-heated gases where high temperatures prevent use of conventional seal materials (Fig. 10).
- Sealing graphitization furnaces used in carbon electrode production where temperatures reach 3000+°F.
- Sealing high temperature interfaces/gaps between nuclear fuel rods.

Further tests are required to address feasibility in the above applications.



**Figure 9:** Chemical processing plant.



**Figure 10:** High temperature furnace door seals.

## ORGANIZATION DATA

### 13. Contact person to handle all arrangements on exhibits, banquet, and publicity.

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# APPENDIX 1

## Invoice for purchase of thermal barrier

02/15/2002 11:31 FAX 4358633848

PROCUREMENT

002

INTERNATIONAL

**Techniweave Inc.**

112 Airport Drive

Rochester, NH 03867

Phone: (603) 330-5800

Fax: (603) 330-5801

Remit To: P.O. Box 414034 Boston, MA 02241-4034

**INVOICE**

Invoice No. ICG01755  
Date 9/5/2001  
Order No. ED3070  
Shipper ID S0001867  
Order Type Sales Order  
Customer ID THIOKOL

**BILL TO:**

**THIOKOL PROPULSION**  
ACCOUNTING DEPARTMENT  
PO BOX 707  
MS T12A  
BRIGHAM CITY, UT 84302-0707

**SHIP TO:**

THIOKOL PROPULSION  
BLDG. M3 RECEIVING  
9160 N.HWY 83  
THIOKOL, UT 84307

PAGE 1

F.O.B. POINT		SHIP VIA		ORDERED BY		CUSTOMER P.O. NO.	
Rochester, NH		Fed Ex Next Day Air				M2SX044	
ORDER DATE		TERMS		SALES PERSON		SITE	
9/5/2001		Net 30 Days				BRAID	
PART NUMBER		QUANTITY	UNITS	QTY SHIPPED	PRICE	DISC %	EXT. PRICE
STYLE9023 Thermal Barrier, .26 dia Carbon Braid		90.0000	FT	90.0000	150.0000	0.00	13,500.00

SEP 17 2001

Sales Total		13,500.00
Shipping & Handling		0.00
Misc. Charges		0.00
Tax Total		0.00
Paid		0.00
<b>TOTAL</b>		<b>13,500.00</b>

77028 767471

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## APPENDIX 2

### Additional Developers

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Cory Smith	cory.smith@THIOKOL.COM
Brian Smith	smithbd@THIOKOL.COM

## APPENDIX 3

### References

- <sup>1</sup> Bauer, Paul, "Development of an Enhanced Thermal Barrier for RSRM Nozzle Joints," AIAA-2000-3566, July 2000.
- <sup>2</sup> Bauer, Paul, "MNASAs as a Test Bed for Carbon Fiber Thermal Barrier Development," AIAA-2001-3454, July 2001.
- <sup>3</sup> Totman, Pete, Andrew Prince, Doug Frost, Paul Himebaugh, "Alternatives to Silicon Rubber Thermal Barrier in RSRM Nozzle Joints," AIAA-99-2796, July 1999.
- <sup>4</sup> Ewing, Mark, J. R. McGuire, B. B. McWhorter, D. L. Frost, "Performance Enhancement of the Space Shuttle RSRM Nozzle-to-Case Joint Using a Carbon Rope Barrier," AIAA-99-2899, July 1999.
- <sup>5</sup> Steinetz, B.M. and Dunlap, P.H., "Development of Thermal Barriers for Solid Rocket Motor Nozzle Joints," NASA TM-209278, June 1999.
- <sup>6</sup> Steinetz, B.M. and Dunlap, P.H., "Feasibility Assessment of Thermal Barrier Seals for Extreme Transient Temperatures," NASA TM-208484, July 1998.

## **APPENDIX 4**

### **Web page citations of successful full-scale RSRM firings with thermal barrier**

[http://www.aviationnow.com/avnow/news/channel\\_tech.jsp?view=story&id=news/ssrb1102.xml](http://www.aviationnow.com/avnow/news/channel_tech.jsp?view=story&id=news/ssrb1102.xml)

<http://www1.msfc.nasa.gov/NEWSROOM/news/releases/2001/01-186.html>